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PLASMA ACCELERATOR

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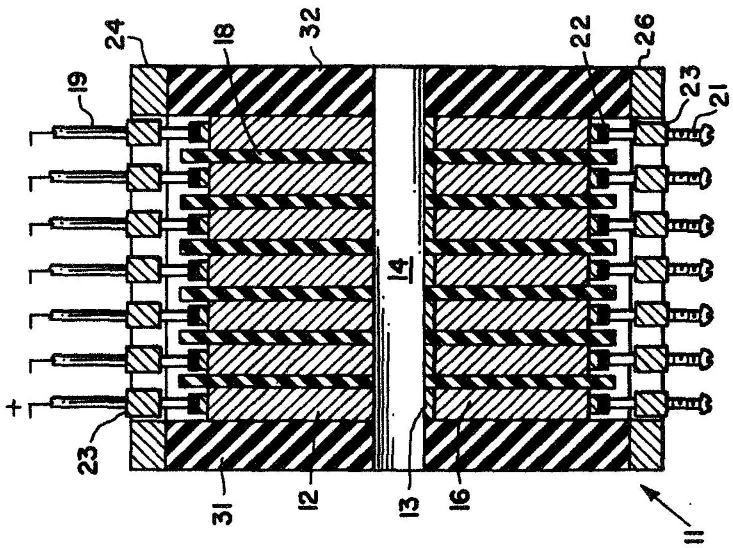

FIG. 2

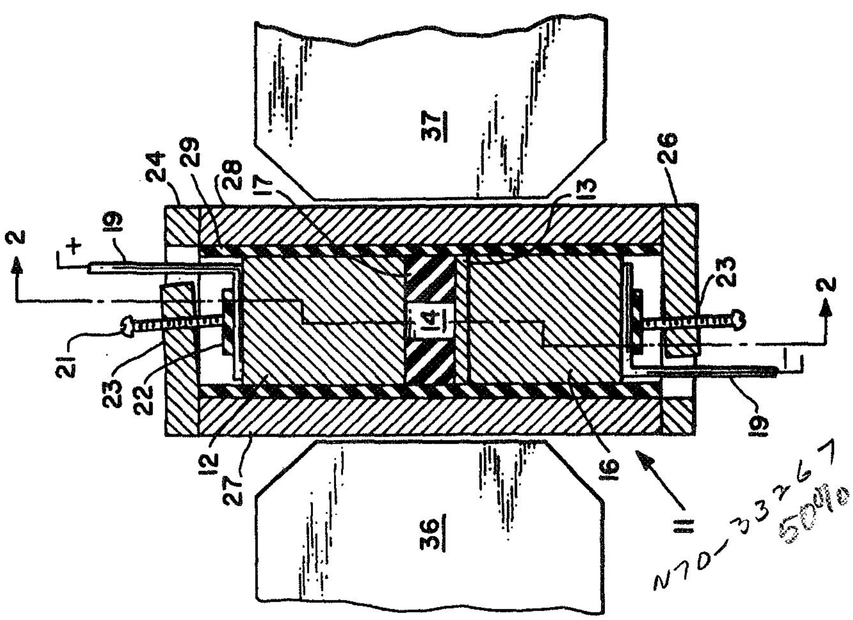

FIG. I

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PLASMA ACCELERATOR

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10 Claims. (Cl. 315—111)
(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates generally to a plasma accelerator, and more particularly to a steady flow, linear, direct current, electromagnetic, crossed-field accelerator.

An apparatus for accelerating an ionized gaseous body, or plasma, to the state required by space age applied science and laboratory experimentation, has been the object of intensive research. A suitable accelerator has many important, potential applications, including use as a source of high-speed flow for aerodynamic testing, as a source of high-speed plasma for research in magnetoplasmadynamics, and as a propulsive system for space vehicles. An especially pertinent area of interest in the ultilization of a steady flow accelerator lies in the laboratory reproduction or simulation, for test and study, of as many as possible of the atmospheric reentry conditions of velocity, temperature, and density, to which space vehicles are exposed.

It has previously been proposed to utilize the prior art electrostatic force principle, as in ion guns and ion engines, in the design of the desired accelerator. However, it has been found that the density of charged particles produced in a device of this type is many orders of magnitude too small for the uses contemplated. It has been further suggested that, if a beam of ions of the necessary density cannot be produced in this manner, the required density could be obtained by putting a relatively small percentage of ions in some gas, accelerating these charged particles electrostatically, and letting them collide with and thereby accelerate the neutral molecules of gas. However, this operation is also found to be unworkable for any reasonable density of gas, such as that existing at 100,000 feet, because of the space charge effect. The space charge due to the ion density required in the accelerating section is estimated to be in the billion-volt class.

The obvious way to overcome space charge effects is to build up essentially equal number densities of positive ions and negative electrons in the accelerator; but if this condition is had initially, application of an electric field to the accelerator will separate the oppositely charged particles until a sufficient space charge is again built up to prevent further separation of the particles, and no net increase in momentum can be obtained.

Accordingly, it is an object of the present invention to provide a novel plasma accelerator.

Another object of the instant invention is to provied a high-density plasma accelerator capable of steady flow operation.

A further object of this invention is to provide a plasma accelerator wherein neutralization of positive ions through contact with the accelerator wall is largely eliminated.

The foregoing and other significant objects are attained in the instant invention by the provision of an accelerating channel having crossed electric and magnetic fields. The fields are oriented normally to each other, and the charged particles of the plasma flowing through the channel are accelerated by a force calculable from the Lorentz equation. In addition to applying the electric field in a plane normal to that of the magnetic field, the electric field is also slanted in an axial, downstream direction so as to cause the positive ions of the plasma to flow nearly parallel to the channel axis; thereby reducing neutralizing contact of the ions with the channel wall. The slanted electric field is provided by a plurality of axially spaced, segmented electrodes which comprise opposing channel walls. The cathodes of the segmented electrodes also serve as thermionic emitters which, when heated by the plasma flow, emit an electron current. The electron current passes through the plasma flow and is collected by the segmented anodes of the opposite channel wall. The driving force on the plasma is dependent upon both the density of the electron current passing therethrough, and the induction of the imposed magnetic field.

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A more complete appreciation of the invention and many of the attendant advantages thereof will be readily apparent as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 is a vertical sectional view of the accelerator, taken along a plane normal to the channel longitudinal axis;

FIG. 2 is a longitudinal sectional view of the accelerator, taken along lines 2—2 of FIG. 1;

FIG. 3 is a schematic wiring diagram illustrating a manner of connecting the plurality of electrodes of the instant invention to unidirectional sources of potential, to provide both a vertical and a horizontal potential gradient; and

FIG. 4 is a schematic diagram illustrating the orientation of the electro-magnetic field relative to the accelerator channel.

Referring now to the drawings, wherein like reference numerals designate identical or corresponding parts throughout the several views, the accelerator 11 of the present invention is illustrated, in FIGS. 1 and 2, as comprising a plurality of axially spaced pairs of electrodes 12–13, positioned so as to form an axial flow channel 14 between the confronting surfaces thereof. It will be noted that the electrode 12 serves as the positive electrode, or anode, and the electrode 13 as the negative electrode, or cathode. It will also be obvious that the anode 12 is much thicker than the cathode 13; the cathode 13 being mounted upon a conductive element 16, the combined thickness of cathode 13 and mounting element 16 approximating that of anode 12. This thickness of material is desirable to enable the electrical connections to the electrodes to be made at relatively cool locations. A satisfactory high-temperature material which may be utilized for the anode 12 and the mounting member 16 is graphite. The cathode material 13 must be selected with regard both to its melting point and to its thermal emission rate. Several cathode materials have been suitably employed; three of such materials being: lanthanum hexaboride, pure tungsten, and 2 percent thoriated tungsten. The 2 percent thoriated tungsten has been found to best combine the properties of high melting point and electron emissivity. It may be observed that the accelerator 11, as shown, consists of seven pair of electrodes. However, the number of electrode pairs may be more or less than the seven shown, the number being dependent upon the degree of electric field uniformity desired, and upon the length of acelerator desired.

The plurality of electrode segments 12, 13 are separated by elongated rectangular insulating strips 17; the strips forming the sidewalls of channel 14. An insulating spacer member 18, FIG. 2, is positioned between each of the axially spaced electrodes 12, 13. A preferred material

for the insulating members 17, 18, possessing excellent high temperature insulating properties, is boron nitride.

Electrical contact to the electrodes 12, 13 is made through individual L-shaped brass plates 19; the electrical contacts 19 being pressed into engagement with the outer surfaces of anode 12 and the cathode mounting member 16. Pressure is applied to the electrical contacts and electrode assembly through screws 21, the screws being insulated from electrical contact plates 19 by members 22. The screws 21 are threaded through cantilevered arms 23, which extend laterally from upper and lower wall members 24, 26, to exert the desired pressure.

The electrode assembly is housed in a nonmagnetic, stainless-steel casing consisting of upper and lower wall members 24, 26, and side walls 27, 28. A liner 29 of insulating material, such as boron nitride, is positioned between the side walls and the electrodes to prevent shorting. The ends of the electrode assembly are enclosed by relatively thick insulating members 31, 32, FIG. 2. The electrode assembly and wall members are secured together into an integral unit by clamps or bands, not shown, fastened to the outer, metallic wall members.

Alternatively, it is contemplated that the accelerator casing may be formed from a cast ceramic block; rather than individual wall members surrounding the electrode assembly and secured together. Individual holes to receive the electrodes would then be cut in one wall of the block, and a flow channel formed through the ceramic block. If desired, the emitting cathodes can be mounted on a movable pedestal, for movement away from the flow channel. This construction enables the emitting wall to be lowered away from the accelerator to permit activating of the thermionic emitters by heating means other than the plasma flow, without heating of the whole accelerator during the period required to activate the emitters.

The electrical circuit for accelerator 11 is schematically illustrated in FIG. 3. As shown, a vertical electric field is established between each anode 12 and cathode 13 by an individual direct current potential source 33. An additional potential source 34 is arranged between each axially spaced electrode pair 12, 13, to set up an axial or horizontal electric field in the downstream direction. The net effect of these two potential gradients is to create a slanted electric field which accelerates and directs, in conjunction with an imposed magnetic field, the charged particles supplied to flow channel 14.

The accelerator magnetic field is applied by an electromagnet; the poles 36, 37 of which are shown in FIG. 1. The magentic field is applied across channel 14, perpendicular to the slanted electric field and to the channel axis.

In laboratory experiments, with one embodiment of the above described accelerator, the following parameters were used. The accelerator 11 was housed in a test chamber, not shown, constructed of nonmagnetic stainless steel, 8 inches square and 24 inches long. The chamber was evacuated to a pressure of 80 mm. Hg. Magnetic poles 36, 37 passed through the walls of the test chamber and formed a gap of 1¾ inches with an area of 2½ x 4½ inches. A magnetic field of 1.2 webers/$m.^2$ was produced in the gap. The flow channel was 1 cm. square, and the accelerator was 3¼ inches long, with seven electrodes ¼ inch in length separated by ⅛ inch insulators made of boron nitride. The cathodes 13 were made from thoriated tungsten, $^1/_{16}$ inch thick, and the anodes 12 from graphite, 1½ inches thick. The electrode assembly was housed in nonmagnetic stainless-steel walls, with a $^1/_{16}$ inch thick lining of boron nitride between the electrodes and the walls. A potential gradient of 48 volts/cm. in a vertical direction and 4 volts/cm. in an axial direction was applied to the accelerator. This gave a current density across the flow channel of 16 amperes/$cm.^2$. Acceleration of the plasma was verified by Pitot tube measurement of the change in stagnation pressure at the accelerator exit, and by static pressure measurements at the entrance and exit of the accelerator channel. The above parameters are merely illustrative of one embodiment of the instant invention; and the enlargement or reduction in scale of accelerator physical dimensions and field strengths, or the substitution of other suitable materials for those employed, are contemplated by the inventors thereof.

The principle of operation of the disclosed accelerator 11 is based on the Lorentz equation, $F=j\times B$. The term F of the equation may be defined as the driving force per unit volume exerted on the plasma to be accelerated; j as the density of electron current flow through the plasma; and B the magnetic induction of the accelerator field. The electron current flow through the plasma is produced by the electric field created between pairs of electrodes 12, 13. Electrons are emitted from cathodes 13, pass through the plasma, and are collected by anodes 12. The magnetic field is set up perpendicular to both the direction of plasma flow and of electron current flow by poles 36, 37. The charged particles of the plasma introduced into the crossed-fields of the accelerator 11 experience a driving force, normal to both the magnetic and the electric fields, which accelerates the particles in an axial, downstream direction. The positive ions of the plasma, in turn, collide with and propel neutral gaseous molecules along the accelerator channel.

In FIG. 4, the various factors set forth above are shown oriented with respect to the accelerator flow channel 14. The magnetic field B is applied across the channel perpendicular to and into the paper. The electric field E is applied across channel perpendicular to the magnetic field, but slanted with respect to the channel longitudinal axis. Electric field E produces an electric current whose density is j, and the plasma experiences an accelerating force $j\times B$ per unit volume.

To provide a clearer understanding of the instant invention, the operation of the disclosed plasma accelerator will now be described. A plasma flow is introduced into the left hand side, FIG. 2, of accelerator 11. The source of the plasma may be a plasma producing apparatus as is described in the co-pending application of Arlen F. Carter, Serial No. 178,215, filed March 7, 1962, NASA Case No. 147. The cross electrical and magnetic fields have been activated prior to introduction of the plasma into channel 14. The plasma upon entry into channel 14, at a temperature of approximately 5,500° K., heats up the cathodes 13 to a temperature at which thermionic emission takes place. The electron current emitted from the cathodes 13 passes through the plasma to be accelerated, and is collected by anodes 12. The charged particles of the plasma flow experience a driving force, calculable from the Lorentz equation set forth above, which accelerates the particles along downstream, cycloidal paths. The horizontal, or axial, potential gradient set up between the axially spaced electrode pairs 12, 13, serves to slant the electric field with respect to the accelerator axis; the electric field thereby being tailored to direct the Lorentz force substantially parallel to the channel axis. Therefore, the slanted electric field produced by the axially spaced, segmented electrodes, prevents loss of positive ions through neutralizing collisions with the channel walls by directing the ions away from the walls, in an axial, downstream direction. The positive ions, being accelerated through channel 14 by the crossed fields, in turn propel neutral gaseous molecules along the length of the accelerator channel through collision processes. The accelerated plasma then emerges from the right hand side of the accelerator, FIG. 2, for utilization in the various test, experimental, and propulsion applications previously set forth.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A plasma accelerator comprising: a plurality of electrode pairs spaced along a linear axis, a plasma flow channel defined by the confronting surfaces of the electrodes of each of said pairs, one electrode of each electrode pair comprising a cathode adapted to be heated to its electron emission point by the plasma flow through the channel, an electrical circuit interconnecting said plurality of electrode pairs, said circuit being adapted to provide an electric field across said channel directed at a slant angle to said linear axis whereby the positively charged particles of the plasma are directed along the channel axis to prevent neutralizing collisions with the channel walls, and means for providing a magnetic field across said channel directed perpendicular to said electric field, said means being positioned on opposite sides of said flow channel.

2. A plasma accelerator as defined in claim 1 wherein each of said electrode pairs consists of a cathode and an anode, and said electrical circuit includes: a unidirectional potential source connected across each cathode-anode pair for providing a potential gradient normal to said linear axis, and a unidirectional potential source connected between each axially spaced cathode-anode pair for providing an axial potential gradient.

3. A steady flow, linear, high-density plasma accelerator comprising: a flow channel having a longitudinal axis, a plurality of positive electrodes spaced along said longitudinal axis and comprising a first wall of said channel, a plurality of negative electrodes spaced along said longitudinal axis and comprising a second channel wall opposing said first wall, a pair of elongated insulating strips extending parallel to said longitudinal axis and positioned between said positive and negative electrodes, said strips comprising opposing third and fourth walls of said channel, an electrical circuit interconnecting said positive and negative electrodes, said circuit being adapted to provide an electric field across said channel directed at a slant angle to said longitudinal axis, and means, positioned on opposite sides of said flow channel, for providing a magnetic field across said channel directed perpendicular to said electric field.

4. A plasma accelerator as defined in claim 3, wherein said electrical circuit includes: unidirectional sources of potential connected across opposing pairs of positive and negative electrodes for providing a potential gradient perpendicular to said longitudinal axis, and a unidirectional potential source connected between each axially spaced pair of positive and negative electrodes for providing an axial potential gradient.

5. A plasma accelerator as defined in claim 3, wherein said negative electrodes comprise thermionic emitters adapted to be heated to electron emission by the plasma flow through the channel.

6. A plasma accelerator as defined in claim 3, wherein an insulating spacer member is positioned between each of said plurality of positive electrodes and between each of said plurality of negative electrodes.

7. A steady flow, plasma acelerator comprising: a plurality of cathode-anode pairs spaced along a linear axis, insulating members positioned between and separating said cathode-anode pairs, said cathode-anode pairs defining a flow channel along said linear axis, the cathodes of each of said pairs consisting of a material having a high rate of electron emissivity, an electrical circuit interconnecting said cathode-anode pairs, said electrical circuit including: a unidirectional potential source connected across each cathode-anode pair for providing a potential gradient normal to said linear axis, and a unidirectional potential source connected between each axially spaced cathode-anode pair for providing an axial potential gradient; and means for providing a magnetic field across said channel directed perpendicular to the electric field created by said vertical and axial potential gradients, said means being positioned adjacent said flow channel.

8. A plasma accelerator as defined in claim 7, wherein said cathode material is lanthanum hexaboride.

9. A plasma accelerator as defined in claim 7, wherein said cathode material is pure tungsten.

10. A plasma accelerator as defined in claim 7, wherein said cathode material is thoriated tungsten.

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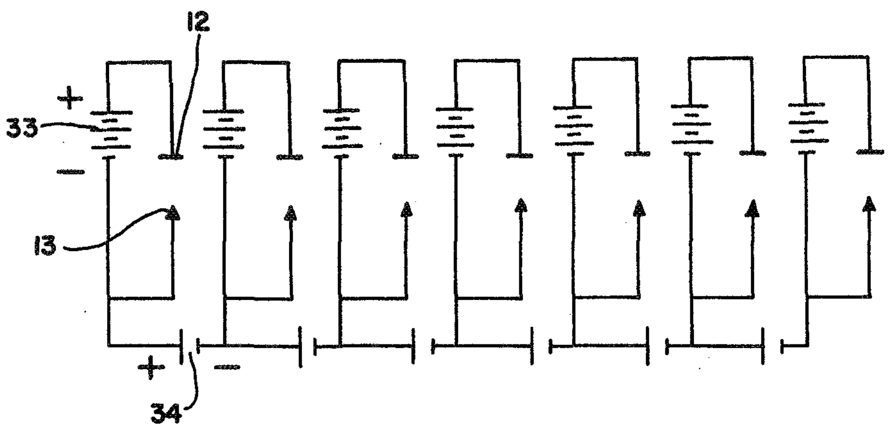

FIG. 3

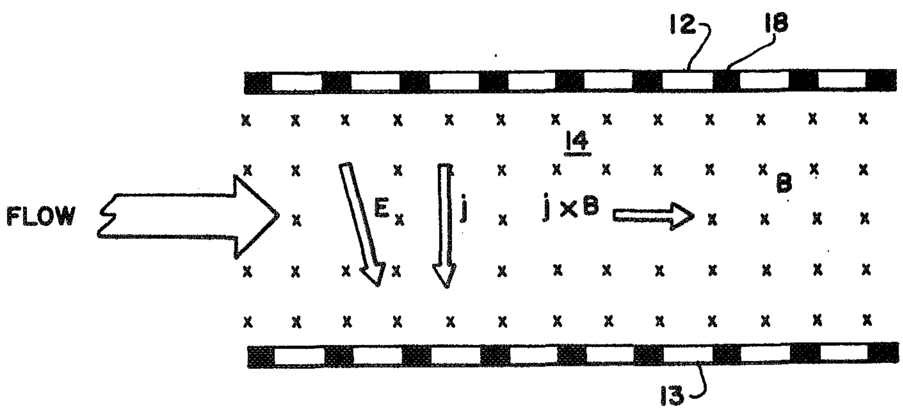

FIG. 4

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